EFFECT OF CURRENT PULSE SHAPE ON DRIVING METAL/WATER CHEMICAL REACTION

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Abstract

Pulsed electrical activation of a trigger wire embedded in a reactive metal powder-water mixture triggers a fast and highly energetic chemical reaction in the mixture. The major variable determining the extent of the reaction is the primary stored energy. The reaction efficiency, however, depends largely on the current pulse shape, which is characterized by the circuit parameters. In order to make the most efficient use of the pulsed power in driving the reaction the trigger wire should carry the current to near its peak value immediately before its explosion. This requirement uniquely determines the cross sectional area of the wire running through the center axis of a cylindrical slurry system, for a given set of primary energy and circuit inductance. As long as this requirement is fulfilled, the total mass of the wire (or the length) dictates the cross sectional area of the slurry around the wire which is going to undergo the reaction. There appears to be a range of the circuit inductance which helps generate a series of pulse shapes, effective for triggering the reaction in the slurry.

Introduction

Fast electrical activation of some metal conductors in a water environment has potential applications in fields such as fast hydrogen generation and fuse opening switches. The activation, achieved by ohmic heating when a current pulse is applied to the metal/water system, is crucial to dispersing the metal finely in water. When finely dispersed, the metal particles can sustain the reaction with water despite the oxide layer rapidly formed on their surface. Previous investigations[1,2,3] on aluminum/water reaction showed that the electrical energy input for the activation can be reduced by incorporating various experimental techniques. The techniques include alloying of aluminum by lithium, multiple-pulse application, and premixing of metal powder with water. The common goal of these methods is achievement of surface contacts between metal and water through non-electrical means.

Among these, the premixing is particularly attractive due to its high energy efficiency in advancing the reaction. In the premixing method, the aim of the activation is to trigger and sustain the reaction between the already-mixed reactants, rather than to disperse the metal within water. Due to high exothermicity associated with the reaction, it is expected that the reaction, once triggered by electrical means, proceeds rapidly. Since the mixture has a low electrical conductivity, the pulse is initially discharged through a triggering conductor, normally wire, embedded in the medium.

The efficiency of the reaction, defined as the ratio of the chemical energy output to the electrical energy input, has been studied as a function of the pulse shape which was varied by adjusting the circuit parameters. Success in the initiation of the reaction was found to depend on a careful matching of the primary energy to the physical dimensions of the trigger and the reactants. Some details of the experimental results will be presented in this paper.

Experimental

The electrical circuit used in the present work and the details of the energy dissipating medium are shown in Fig. 1. The reactants and the trigger wire were placed in a polyethylene cartridge with a brass electrode at each end. Aluminum wire was used as the trigger which was either 5 or 10 cm long. The reactants consists of the stoichiometric mixture of aluminum powder (-325 mesh size) and deionized water. The mass of wire is less than 2% the mass of the powder. One electrode, used as a diaphragm, ruptures when the pressure inside the cartridge reaches a certain value. The cartridge was placed inside a steel pressure chamber and proper electrical connections were made between the units.

The product gas was collected in the chamber of 2 l

* This work was supported by the Office of Naval Technology

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUN 1991	**N/A**	**-**

4. TITLE AND SUBTITLE	
Effect Of Current Pulse Shape On Driving Metal/Water Chemical Reaction	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Surface Warfare Center, White Oak Laboratory Silver Spring, MD 20903-5000**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License

14. ABSTRACT

Pulsed electrical activation of a trigger wire embedded in a reactive metal powder-water mixture triggers a fast and highly energetic chemical reaction in the mixture. The major variable determining the extent of the reaction is the primary stored energy. The reaction efficiency, however, depends largely on the current pulse shape, which is characterized by the circuit parameters. In order to make the most efficient use of the pulsed power in driving the reaction the trigger wire should carry the current to near its peak value immediately before its explosion. This requirement uniquely determines the cross sectional area of the wire running through the center axis of a cylindrical slurry system, for a given set of primary energy and circuit inductance. As long as this requirement is fulfilled, the total mass of the wire (or the length) dictates the cross sectional area of the slurry around the wire which is going to undergo the reaction. There appears to be a range of the circuit inductance which helps generate a series of pulse shapes, effective for triggering the reaction in the slurry.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**4**	

capacity which had been under vacuum before the pulse application. The gas pressure was read after it cooled down and its content was analyzed using gas chromatography. A current transformer and a resistive divider were used to measure the current through the reactants and the voltage developed across them.

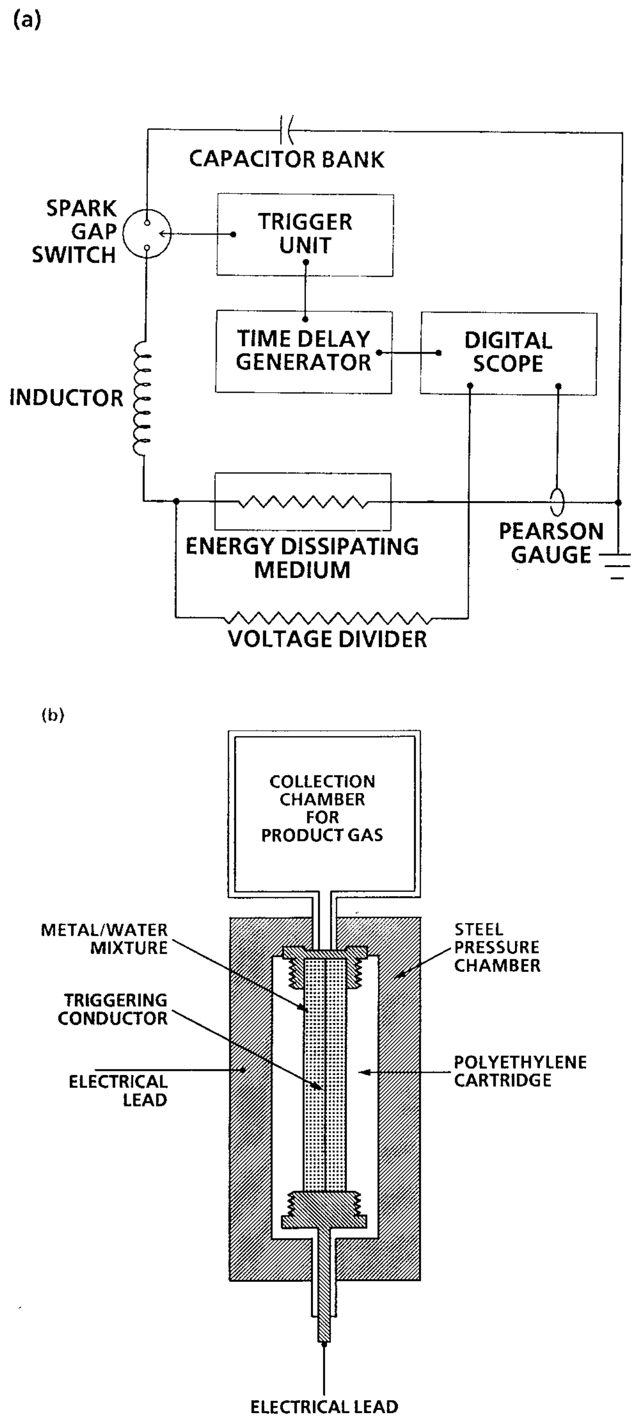

Fig.1. (a) Electric circuit and (b) detailed diagram of the energy dissipating medium.

Results and Discussion

Current trace of exploding aluminum wire residing in the slurry is determined by the physical dimension of the wire and the nature of the interaction between the wire and the medium when other circuit parameters are kept constant. Shown in Fig. 2(a) is the current trace as a function of the diameter (cross section) of the wire. In Fig. 2(b) the percentage of the slurry which underwent reaction is plotted as a function of the diameter and plotted in a crude sense as a function of zero current (the end of discharge) time. The smaller the wire diameter the earlier the wire explodes and less energy is dissipated through the medium. The total dissipated energy increases with the wire diameter up to the cross section of 0.95 mm^2 while the dissipated energy per unit cross section of the wire is maximized at an area of 0.63 mm^2. It is reasonable to assume that the efficiency of the wire in triggering the reaction depends on both the local temperature created by and the cross sectional area of the slurry covered by the exploding wire. The area covered should be a function of both the total dissipated energy and the rate of the dissipation (power).

The importance of the dissipation rate is based on the following reason. The shock wave generated by an exploding wire was found to be proportional to both the peak voltage across the wire and the wire mass[2]. The voltage rise is directly related to the rate of dissipation. If the rate is low, even a dissipation of a long duration cannot effectively formulate a shock wave front and the subsequent pressure wave. In such a circumstance the exploding wire would not likely cover a large area of the slurry around it.

Based on the reasons presented above it is easy to see why the wire of smallest diameter does not have much triggering power. The wire of large diameter, on the other hand, neither reaches a temperature which is high enough to trigger the reaction nor dissipates the energy fast enough to generate an effective shock or pressure wave. Thus, there should exist a certain wire diameter or a range of diameter which can, upon explosion, initiate the slurry reaction effectively. The results shown in Fig. 2(b) actually support this point.

The results shown in Fig. 2(b) can be interpreted from a different view point which regards the trigger wire as a mere energy converter. At a given set of circuit parameters the converter transforms the primary stored energy into a dissipating energy in pulsed form whose amplitude and duration depend on the wire diameter. Efficiency of the converter is measured by the energy efficiency (ratio of the dissipated energy to the primary energy) and conversion time. The most efficient converter dissipates the primary energy with minimum loss and in shortest possible time. This condition can be met if the wire explodes at very near the peak current. The result shown in Fig. 2 (b) roughly supports that this is the case. It is interesting to see that the power of an inductive stored energy in triggering metal/water reaction applies to the slurry system as well as the exploding wire in water[1].

Suppose we change the inductance while keeping the total dissipated energy constant and satisfying the condition of the

peak current explosion. This can be done if we change the wire diameter accordingly. Then each set of circuit parameters should have its own pulse optimized for its effectiveness in triggering. Then the question is whether there is a wide range of inductance which helps generate an effective pulse in triggering the reaction or a unique inductance.

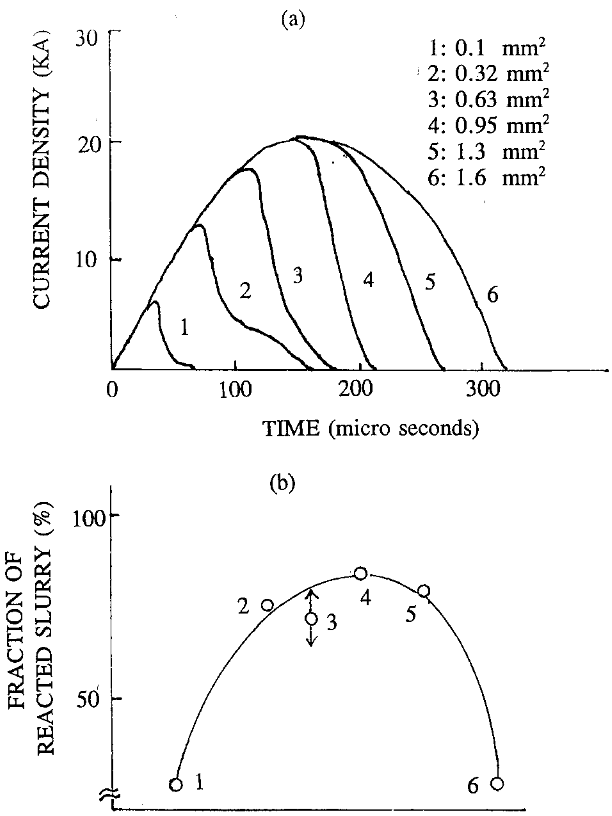

Fig. 2. (a) Current trace as a function of the cross sectional area of wire and (b) the fraction of the reacted slurry as a function of the area.

The current traces satisfying the conditions are shown in Fig. 3(a). As inductance gets larger the wire diameter gets smaller to make the wire explode at the peak current time. Shown in Fig. 3(b) is the corresponding energy dissipation rate (power) profiles. It is seen that the smaller the inductance, the sharper and shorter the energy dissipation rate becomes. It is also seen from Fig. 3(c) that the efficiency of the pulse in triggering the slurry reaction drops somewhat as the inductance becomes larger. But it is not clear from the parameter range studied whether there is a genuinely optimized pulse form.

Decrease in the efficiency for a larger inductance system may be explained by the following factors. First, the large inductor has a higher ohmic energy dissipation, utilizing less of the primary energy for activating the reacting medium. Second, the circuit of larger inductance has smaller wire diameter and smaller peak current, thus delivering the power at lower magnitude. This could result in, as indicated previously, smaller area of the slurry covered.

An interesting question is what would happen if the inductance gets very small, generating a very short, sharp

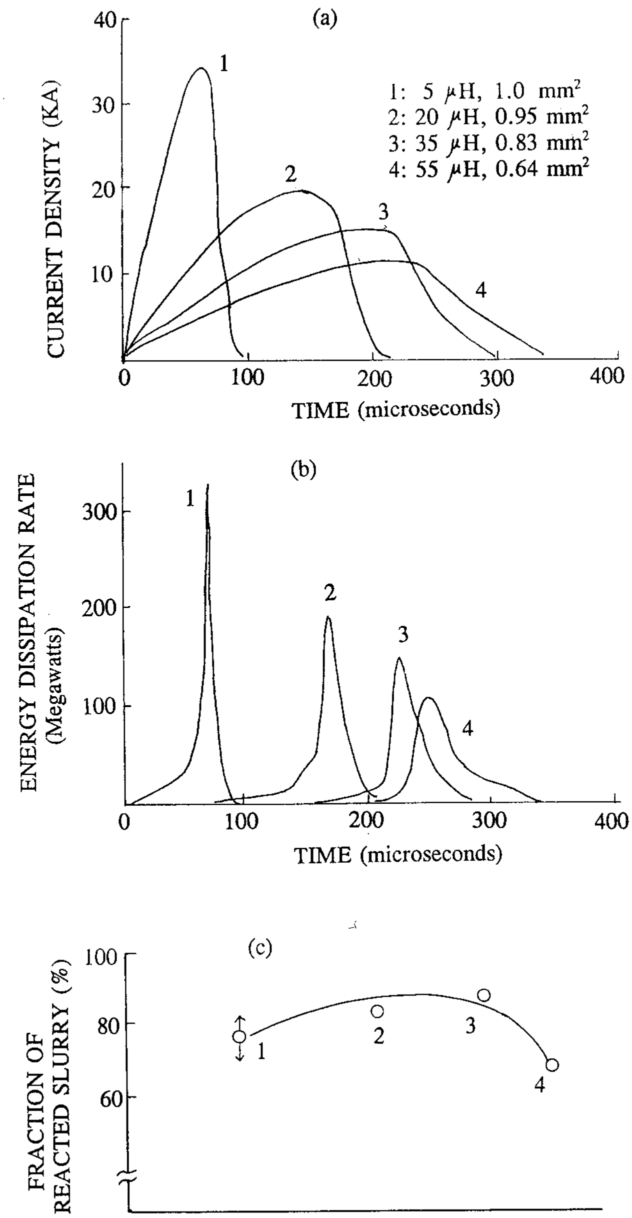

Fig. 3. (a) Current trace as a function of the inductance and the cross sectional area of wire, (b) the corresponding profile of the energy dissipation rate and (c) the percentage of the reacted slurry material as the function of the parameter set.

pulse, much more beyond the range studied in this report. In such a case it is likely that most of the stored energy is converted into a mechanical energy in the form of a shock wave. Then the slurry system would not have any induction time during which it receives a critical thermal energy from the exploding wire, necessary to trigger the reaction. Thus, it is plausible that the triggering efficiency will also drop in such a case.

The questions regarding the inductance can be best answered by using a constant current source of varying magnitude. By adjusting the duration and the magnitude of such current applied to the reacting medium, the effect of pulse shape on the triggering efficiency will be clearly manifested.

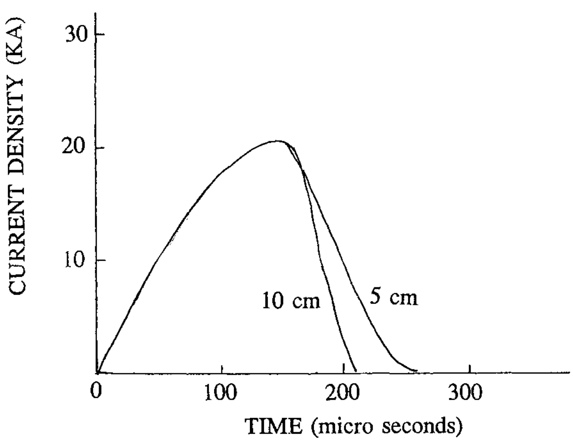

Fig. 4. Current traces of the trigger wire having different length.

Thus far the wire (or the reacting medium) length, parallel to the current direction, has been fixed. Decreasing the length, while keeping other variables of the circuit the same, makes more energy available after the wire explosion, possibly triggering more slurry material per unit wire length. An example which illustrates this case is shown in Fig. 4. It shows the current traces for the two reacting systems of different length along the electric current path, 5 and 10 cm, respectively. For the shorter system the electrical discharge takes longer due to its lower energy consumption for the wire explosion. Also the dissipated energy per unit length is higher for the shorter one, implying that the amount of the reacted slurry material per unit wire length could be higher. Analysis of the reaction product indeed showed that the shorter one triggers over 35% higher slurry per unit length of the wire. For the shorter system, the pulsed discharge could be actually coupled to the slurry reaction[4] whereas the reaction in the longer case could be mainly an aftereffect of the discharge.

Conclusion

The effectiveness of the pulsed power technique in driving aluminum/water reaction has been studied. The reacting system consists of a mixture of aluminum particle/water in a slurry form and an aluminum wire running through the slurry.

Given a primary stored energy the trigger wire should carry the current to near its peak value right before its explosion in order to make the most efficient utilization of the energy. This uniquely determines the diameter of the wire and the range of the wire length at a given circuit inductance. A shorter wire system can trigger higher cross sectional area of the slurry that could undergo the chemical reaction. There is a range of inductance which helps form an effective pulse shape in driving the reaction.

Acknowledgements

The author wishes to thank Dr. R.E. Meger at the Naval Research Laboratory for providing him with experimental facilities and Mr. H.B. Hall for technical assistance.

References

1. W. M. Lee and R. D. Ford, "Reactivity of Al-2.5%Li with water as studied by the exploding wire technique", Met. Trans. B 19, 255 (1988).

2. W. M. Lee and R. D. Ford, "Pressure measurements correlated with electrical explosion of metals in water," J. Appl. Phys., vol. 64, pp. 3851-3854. Oct. 1988.

3. W. M. Lee and R. D. Ford, "Effective coupling of pulsed power to chemically reactive metallic systems", 7th IEEE Pulsed Power Conference, Monterey, Calif. 1989, pp. 981-984.

4. W. M. Lee, "Metal/water chemical reaction coupled to a pulsed electrical discharge", J. Appl. Phys., vol. 69, pp. 6945-6951. May. 1991.